Energy-Efficient Running Aid

This application is a continuation in parts of application # 09/621,238 filed on 07/26/2000 by Brian Rennex.

BACKGROUND OF THE INVENTION

This invention, referred to as a running aid, relates to running braces and in particular to energy-efficient running braces. A running brace augments the effective spring constant of the leg by adding a resilient brace which supports the runner's weight in parallel with the leg. The invention combines the balance and control capabilities of the human foot/leg system with the strength and resilience features of a mechanical brace system.

Around 1890, four running brace patents were issued to Nicholas Yagn, a mechanical engineer in the army of the Emperor of Russia. The first two, U.S. Patent Nos. 420,178 and 420,179, use bow springs, attached to the shoulder and the pelvis, respectively. The second of these incorporates a foot-lift means whereby the top of the bow spring can slide up a plate extending upwards from the runner's waist, during swing phase. However, there is no workable means to trigger this sliding. U.S. Patent No. 438,830 was based on an unworkable design to fill a flexible tube with compressed gas to achieve a resilient brace. The fourth, U.S. Patent No. 406,328 comprised telescopic springs and an unworkable telescopic release for leg lift in swing phase.

More recently, Chareire, U.S Patent No. 4,872,665, provides for a running brace comprising telescoping gas springs and a leg-lift means further comprising a ratchet joint. In principle, this invention should, in principle, work but it is exceedingly complex and it would be difficult and expensive to manufacture. In addition, it is doubtful that the trigger system for braking and releasing the rachet joint is versatile. Another drawback of the design is that compressive telescopic means necessarily entail friction losses, and this is especially the case with gas springs. Also, the travel of this running brace is limited by the requirements of telescopic overlap.

Dick, U.S. Patent No. 5,016,869, discloses another complicated and heavy (50 lbs.) bipedal device which is intended to ensure a long travel and leg lift in swing phase, and it appears that the runner's weight is not supported in parallel with the runner's legs in which case the device is equivalent to a series-support running shoe and not a running brace. A number of links, cables and springs are

incorporated in the involved design as to make the device rather cumbersome. Rennex disclosed an invention in U.S. Patent No. 5,011,136 to provide for asymmetric leg-length travel in impact and thrust and to provide for high leg lift. It features a pair of telescopic springs and a trigger and ratchet system to achieve this asymmetry. The disadvantages of this design are its complexity and friction losses in the compressive telescopic design. Other provisions attempted to address the problem of optimized force curves to achieve high performance and high impact energies without injury.

This inventor was not able to find prior art for harnesses specifically designed for coupling a running brace to the human body. One related example is disclosed by Petrofsky in US Patent No. 5,054,476, which uses support elements coming up the sides of a walker with cuffs attached at the thigh, waist , and armpit levels to give the walker support. This design does not provide for comfortable support for the brace loads of several gees needed for a running brace. A second example is disclosed by Spademan in US Patent No. 5,002,045, in which cuffs or straps attached to the limbs (or the waist) on either side of a joint are tightened as the limbs bend around that joint. The current patent is distinguished from both of these examples of prior art by virtue of the fact that the brace load is distributed in an adjustable manner over a substantial area of the human body for optimal comfort, and the automatic harness tightening is powered by the impact load on the brace, and not the relative motions of adjacent human limbs or elements. These features are adapted for the demanding requirements of running-brace support where load forces are large -- several gees -- and the human body is erect. Virtually all harnesses for high loads require the user to be sitting, and, hence, they are not useful for a running brace.

Regarding the prosthetic applications of the novel, tibia-located self-guiding springs of this invention, Phillips discloses in U.S. Patent # 5,458,656 a leaf spring guided by telescoping tubes and hingeably-attached to the top knee pylon. The drawback of this invention is that the telescoping guide is costly and the deflection of the single spring is limited. Kania discloses in U.S. Patent # 5,653,768 a pair of leaf springs fixedly attached to the top knee pylon and passing one through the other. The limitation of this design is that the spring deflection is limited because the leaf springs are not hingeably connected. Likewise Rappoport discloses in U.S. Patent # 5,509,936 a pair of leaf springs fixedly attached to the top knee pylon -- with limited deflection. The advantage of the tibia spring in the current invention is that the vertical bow springs are hingeably attached, allowing optimization of the spring system in terms of ample deflection, constant force-curve, and low weight.

Also, cost is reduced by eliminating the guide system.

SUMMARY OF THE INVENTION

This "running aid" invention relates to passive (spring-actuated) running aids for ortheses, prostheses, and robots. The full invention is an leg ortheses or an energy-efficient running brace. It is a running brace which acts in parallel with a runner's leg to support the runner during stance phase and to capture all foot-impact energy, preferably with the optimal constant-force curve, for use to thrust said runner back into the air during toe-off. Moreover, several structural components of the full invention also have applications for prostheses, robots, and robotic exoskeletons to enhance human performance. These structural elements include a novel variable-angle knee-lock, a novel self-guiding/constant force bow spring, a novel pulley-based/constant-force bow spring, a novel brace/ankle system, a novel front/back brace leg which couples to the runner's pelvis in the front and back of his pelvis, novel means to ensure hyper-extension for "constrained hyper-extension" knee locks (referred to as self-locking), a novel and very cheap means to prevent "bounce-back" with self knee locks, and a novel load-tightening full harness. In addition to allowing faster running with less energy, the running brace protects the legs, joints and feet from impact injury since it eliminates impact forces above a safe level. The running brace is coupled to the runner via a body harness. This coupling must be located above the leg to allow it to rest as much as possible during the stance phase.

This running aid provides an essential improvement over prior art in the following ways. The force curve of the leg spring is optimal for quick support and maximum energy storage. The problem of a lock -- to switch the running brace from a stiff spring mode during stance to free bending mode during swing phase -- is circumvented with self-locking designs, and it is solved with either a novel variable-angle knee lock or a slider lock. The problem of leg-length asymmetry is overcome with a shaped brace foot, and the comfort problem is addressed with a novel load-tightening pelvic/body harness which distributes the impact load over a substantial portion of the body above the knees.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic side view of the running aid generic to the various

embodiments of the invention.

Figure 2 shows side views of series bow springs for use in the first embodiment of the invention.

Figure 3 shows side and top views of perpendicular-bow self-guiding springs for use in the first embodiment of the invention..

Figure 4 shows a side view of a tibia perpendicular-spring/brace-foot assembly for use in the first embodiment of the invention.

Figure 5 shows side views of a tibia perpendicular-spring/hinged-brace-foot assembly.

Figure 6 is a side view of the decoupled-bow version of the running aid according to the second embodiment of the invention.

Figure 7 is a front view of the decoupled-bow version of the running aid according to the second embodiment of the invention.

Figure 8 is a side view of the running aid according to the third embodiment of the invention showing a gas spring with a reservoir.

Figure 9 is a side view of the support part of a self-locking knee mechanism of the running aid according to the fourth embodiment of the invention.

Figure 10 is a side view of the 4-bar foot–lift assembly for maintaining clearance of the brace foot above the ground during swing phase according to the fourth embodiment of the invention.

Figure 11 is a front cross-sectional view of the running aid according to the fifth embodiment of the invention showing the variable-angle knee lock.

Figure 12 is a side cross-sectional view of the running aid according to the fifth embodiment of the invention showing the shaft/collar assembly of the variable-angle knee lock.

Figure 13 is a side cross-sectional view of the running aid according to the fifth embodiment of the invention showing the shaft and the collar of the variable-angle knee lock.

Figure 14 is a side cross-sectional view of the running aid according to the fifth embodiment of the invention showing rotation of the shaft with respect to the collar of the variable-angle knee lock.

Figure 15 is a side view of the running aid according to the fifth embodiment of the invention showing a damper for use with the variable-angle knee lock.

Figure 16 is a side view of the running aid according to the fifth embodiment of the invention showing a tibia lock-release for use with the variable-angle knee lock.

Figure 17 is a back view of the cable system allowing the use of a single bow

spring in the sixth embodiment of the running aid.

Figure 18 shows schematic views of the full harness for the running aid.

Figure 19 is a side view of a generic mechanical design for a mechanical load-tightener used in the harness for the running aid.

Figure 20 shows examples of compressible woven harnesses for load-tightening sleeves of the harness for the running aid.

Figure 21 is a side view of an overlap double-pulley load tightener which is an example of a mechanical load-tightening cuff used in the harness for the running aid.

Figure 22 is a side view of a bent-lever load tightener, a jamming load tightener and an inward-force load tightener of the harness for the running aid.

Figure 23 is a side view of a combination mechanical/ weave load-tightener of the harness for the running aid.

Figure 24 is a side view of an arm load-bearing harness for the running aid.

Figure 25 shows a schematic front view of a load-equalizer stay tree which distributes the brace load over various parts of the harness for the running aid.

Figure 26 shows an adjustable harness for the running aid.

Figure 27 shows a side view of a generic brace leg with a circular brace foot, demonstrating graphically how well the brace foot prevents vertical travel of the runner's center of mass throughout stance.

Figure 28 shows a hyperlocker mechanism to guarantee hyper-extension of the self-locking knee mechanism of the fourth embodiment of the invention of Figure 9.

Figure 29 shows a slider for changing the length of a running aid according to the seventh embodiment of the invention.

Figure 30 shows a full-stance brace-foot trigger for locking a slider during stance.

Figure 31 shows a foot-coupling guaranteed release mechanism for release of the slider lock at toe-off.

Figure 32 shows a simple-slider running brace according to the eighth embodiment of the invention, wherein the knee pivot is no longer used.

Figure 33 shows a means to combine an active power source with a passive spring according to the ninth embodiment of the invention.

Figure 34 shows two lockable hydraulic sliders with two and three telescopic members.

Figure 35 shows a knee pivot locked by a lockable hydraulic slider according to the eleventh embodiment of the invention.

Figure 36 shows a self-hyper-locker for guaranteeing hyper-extension at foot strike.

Figure 37 shows a "hyper-extension bounce back" prevention means for prevention of folding of a hyper-extending knee lock at heel strike.

Figure 38 shows a front/back brace leg in which the pelvic coupling is made directly behind and in front of the runner's ischial tuberosity (buttock) rather on the side of the hip.

Figure 39 shows a front/back pack extension for comfortable and optimal pack load support.

Figure 40 shows a four-bar knee joint.

Figure 41 is a schematic side view of the bow shoe showing a low-eccentricity knee-joint straightener.

DESCRIPTION

Figure 1 is a schematic side view of running aid 2 with runner 1 shown in dashed lines to indicate the approximate location and extent of the various elements of the invention with respect to the runner who wears the invention. Running aid 2 comprises harness 3 and two brace legs 9, one on the outside of each leg of runner 1. Each brace leg 9 supports runner 1 when her adjacent foot is in contact with the ground during running, i.e. during the stance phase, as distinguished from the swing phase when that leg is not in contact with the ground. Harness 3 is attached to the runner's pelvis, and each brace-foot assembly 8 is attached to the adjacent runner's foot. Since running aid 2 supports the weight of runner 1 in parallel with her leg, she can rest her leg during the stance phase of the running stride cycle. Since running aid 2 can act as a spring to absorb the impact energy of running and to thrust runner 1 back into the air during leg thrust, runner 1 can both exert less energy while running and avoid injuries related to the impact of running. Later, each design component will be discussed in detail, but, first, here is a quick overview.

In order to be able to swing a brace leg forward and/or run uphill, a swing-phase length-change means is required. One option is knee pivot 6 of Figure 1; another option is simple-slider running aid 561 of Figure 32. In Figure 1, thigh-link 4 is rotatably attached to harness 3 on the top and to knee pivot 6 on the bottom. Spring mechanism 5 is incorporated into thigh-link 4 in the second embodiment of the invention shown in Figure 6, but is may be located elsewhere, e.g., on the back of runner 1 in the sixth embodiment of Figure 17 or in the tibia link 7 as an option of the second embodiment of Figure 6. Or, there can be no spring at all in this running

aid invention, in which case the running aid simply provides support and in which case the design features in the discussion of Figure 5 are crucial to provide the brace leg/foot length asymmetry to match the brace support to the runner's leg action. This "no-spring" variation will be referred to as the tenth embodiment of the invention. As will be seen in the more detailed description of the second embodiment in Figure 6, thigh-link 4 includes a guide means which constrains an element rotatably connected to harness 3 to slide with respect to an element connected to knee pivot, under the action of bucky-bow spring mechanism 10 -- to deliver an impulse to runner 1. Knee pivot 6 connects thigh-link assembly 4 and tibia link 7, and it incorporates the brace-link self-locking mechanism to be detailed later. The bottom of tibia link 7 is attached to brace foot 8 which contacts the ground. Each of these components has one or more specific functions essential to easy, efficient running. These functions will next be previewed in a general sense to prepare the reader for the more detailed discussion of the drawings.

Harness 3 must couple running aid 2 to runner 1 above his leg to ensure that running aid 2 acts in parallel with his leg. Since the g-force of running can be 2-3 g's, there is significantly more weight on harness 3 than would be the case with bicycle riding, for example. Since conventional harnesses actually require the user to sit, in which case most of the weight is borne by the backs of the thighs and the back of the waist loop, these conventional harnesses cannot be used for the running aid harness, as one cannot run and sit at the same time. Also, conventional, "above the knee" orthotics, which comprise a rigid, tapered thigh socket and a lip to receive the weight of the ischial tuberosity at the base of the buttocks, receive perhaps 40% of the load in the thigh tapered region. Since the thighs of able-legged runners change shape due to muscular and tendon activity, these conventional, thigh-socket orthotics cannot comfortably be used for running aid 2. Therefore, the design discussion for harness 3 presents a means to spread the brace load over a substantial portion of the body. The area of harness support indicated in Figure 1 extends from the lower thigh to the chest, but it may also include the arms and shoulders.

Spring mechanism 5 should give runner 1 virtually instantaneous support. The optimal force curve is achieved with a bow spring with a buckling force curve in which the force changes virtually instantaneously to the critical-load value and continues at close to that value as the bow bends further. In the second embodiment of the invention of Figures 6 and 7, this buckling force curve is achieved by pulling the bow ends straight together. Since pulleys are used in this design, it is straightforward to achieve a mechanical advantage which allows, first, reduced bow flexing -- an important feature since there is a tradeoff between flexibility and

strength -- and, second, a de facto changing of gears. Another advantage of the pulley/cable aspect of spring mechanism 5, which becomes bucky-bow spring mechanism 10 in Figure 6, is that it can be located anywhere, e.g., on the sides of the legs, behind the legs, or behind the back. Also, a single bucky-bow spring mechanism can be used for both legs of runner 1. Although a variety of spring systems, such a helical springs with longitudinal, "piston-like" guides, may be used in this invention, the bucky-bow has the distinct advantage of the buckling force curve.

Knee pivot 6 allows the folding of thigh-link 4 and tibia link 7. This, in turn, allows runner 1 to high-kick his leg during swing phase, when the leg is not in ground contact. However, there must be some way to lock knee pivot 6 during the stance phase, when the leg is in ground contact. The strength requirements of this locking are very high due to the leverage about knee pivot 6. And, since runner 1 may sometimes land on a bent knee, e.g., when running uphill, this locking must work when thigh link 4 and tibia link 7 have not yet rotated to be aligned. These lock-design requirements have been the major design hurdle for running-brace prior art. The current invention circumvents this locking problem with a self-locking knee designs of Figures 9 and 36, and it solves it with the variable-angle knee lock of Figures 11-14 and with the hydraulic locks of Figures 32 and 35.

The purpose of brace-foot 8 is to give running aid 2 the same length asymmetry as is the case for the legs of runner 1. The term length asymmetry refers to the fact that the effective length of the leg/foot system of runner 1 (e.g., the distance between the hip pivot and the effective point of contact of her foot with the ground) is several inches shorter for landing (heel-down) than for taking off (toe-off). This length asymmetry results from the presence of the human foot and ankle, and it serves to reduce the leg/foot angle of heel-down relative to that of toe-off, thereby improving running energy efficiency. If a running aid does not feature this same length asymmetry, the timing of brace thrust will be too early for optimal, efficient brace thrust. The just-mentioned self-locking requires that brace-foot 8 be rotatably attached to the runner's foot behind her heel. The drawback then is that brace-foot 8 may rotate so that its front portion will drop below the level of the runner's toe, leading to a tripping hazzard. To avoid tripping, the brace foot must have the design of Figure 10 to lift the front of brace foot 8 during swing phase.

This completes the overview. Now the detailed components of the invention will be described. Figure 2a is a side view showing guided bow spring 426. This first embodiment utilizes "series" bow springs which are almost straight when unloaded and which are loaded by pushing the ends of the bow springs toward each

other -- to achieve a buckling or constant spring force curve (versus deflection). Guided bow spring 426 and spring guide 435 comprise upper guide 438 which is slidingly connected to lower guide 436. Upper guide 438 is rigidly connected to top bowholder 428, and lower guide 436 is rigidly connected to bottom bowholder 430. One or more mini-bows 434 are hingeably connected between bottom bowholder 430 and top bowholder 428. Accordingly, guided bow spring 426 is located in series with thigh link 4 and/or tibia link 7 (see Figure 1), and the runner's impact force forces upper guide 438 to slide down into lower guide 436 and compress mini-bows 434. In like manner, the design of Figure 2b is the same as that of Figure 2a except that there are two spring guides 435 located on either side of mini-bows 434.

Figure 3 shows top and side views of perpendicular-bow self-guiding bows 444. Figure 3a shows a top view and Figure 3b a side view of T-shaped perpendicular-bow system 440 in which one or more mini-bows 434 are oriented perpendicular to one or more other mini-bows 434. The rationale is to take advantage of the resistance to bending in the plane of the wide dimension of a bow. In this case and in general, mini-bows 434 are substantially wider than they are thick. Since mini-bows 434 are hingeably attached to end-plates 448 via hinges 14, if only one mini-bow 434 stack (all parallel to each other) is used, then end-plates 448 can rotate freely with one degree of freedom. As soon as another single one or stack of mini-bows 434 is connected between end-plates 448 with an orthogonal or a substantially orthogonal orientation, each orthogonal mini-bow 434 resists rotation of the orthogonal mini-bows 434 in the orthogonal degree of rotational freedom. The result is that T-shaped perpendicular-bow system 440 resists tilting of one end-plate 448 with respect to the other on the opposite end, and this gives a substantially self-guiding spring system. As mini-bows 434 bow over considerably, this self-guiding, or ability to resist non-axial loads is compromised, but in some applications it eliminates the need for a guide system longitudinal to the perpendicular-bow self-guiding bow 444. Figure 3c shows square-shaped perpendicular-bow system 445 in which one or more stacks of mini-bows 434 are oriented to form a rectangular configuration, and Figure 3d shows triangle-shaped perpendicular-bow system 446 in which one or more stacks of mini-bows 434 are oriented to form a triangular configuration -- the combination of which yields a substantially orthogonal configuration. These are just a few of the many configurations possible for perpendicular-bow self-guiding bow 444.

The advantages of perpendicular-bow self-guiding bow 444 include the following. First and most importantly, a significant travel, i.e., 2-6 inches, of spring compression can be achieved with a bow the length of the thigh and/or tibia of the

runner – due to the possibility of using very thin mini-bows 434. Second, it is easy to manufacture, and the total spring stiffness can easily be varied to "tune the brace for a particular runner. Third, this ease in "changing gears" allows one to use a gear-changing mechanism to engage a variable number of mini-bows to "tune" a running aid for an individual or to "change gears" while running by utilizing a mechanism to engage a variable number of min-bows 434.

Figure 4 shows a side view of a tibia perpendicular-spring/brace-foot assembly 25 for use in the first embodiment of the invention. Tibia perpendicular-spring/brace-foot assembly 25 can also be used for below-the-knee prostheses, the only difference being that upper-tibia pylon 13 connects to the runner's stump instead of to the upper portion of tibia link 7 of Figure 1. The function is the same, namely to absorb and return impact energy of running. Upper-tibia pylon 13 is rigidly attached to upper-tibia end-plate 12, and brace foot 8 is rigidly attached to brace-foot end-plate 11. Front bows 16 bow to the front, side bows 15 bow to the outside, and back bows 17 bow to the back – of the runner, and all are hingeably attached to upper-tibia end plate 12 and brace-foot end plate 12. It is still possible to use the configuration of Figure 3c since both stacks of side bows 15, one on either side of the rectangle, can bow to the outside. This is necessary so as to not interfere with the runner's other foot. Tibia perpendicular-spring/brace-foot assembly 25 absorbs and returns the runner's impact energy without need for a separate, longitudinal guide system because of the self-guiding capability described above. Notice that the bottom of brace foot 8 is curved. The shape of this curve is critical to optimize running performance, and this point will be explained in the discussion of the next figure. Figure 4b shows tapered bow 35 which can be used for any of the bow springs discussed herein. Its purpose is to make the rise of the bow force curve to the constant buckling value more gradual in case this is needed for comfort concerns. The amount of taper controls the force curve very precisely and easily.

Figure 5 shows side views of tibia perpendicular-spring/hinged-brace-foot assembly 27. Figure 5b shows the landing at heel-down, and Figure 5a shows the toe-off at take-off. Tibia perpendicular-spring/hinged-brace-foot assembly 27 is now hingeably connected to brace foot 8 via brace-foot end-plate 11, rigidly attached to brace-foot end mount 18, and ankle pivot 23. Brace-foot return spring 22 tilts forward brace foot 8 against brace-foot rear stop 19 in swing phase. At heel-down brace heel 24 impacts the ground. During stance, as the runner continues forward, tibia perpendicular-spring/hinged-brace-foot assembly 27 rotates forward, like an inverted pendulum, until brace-foot end mount 18 impinges brace-foot front

stop 20 – at which time brace-foot 8 rocks forward over brace forefoot curved bottom 21 until toe-of. Regarding the below-knee prosthesis application, the advantage of this design is that all of the impact energy is stored in perpendicular-spring/hinged-brace-foot assembly 27 with its constant-force curve, and this energy is returned to thrust at toe-off at the time when it is best utilized. Prior art prostheses which store energy in heel flat springs and flexing bow shins either give back the energy too soon, or they give it back with a linear force curve which does not couple well with the runner's push-off action. That is, the spring force is too weak at the end of take-off. Whereas, for a constant-force spring, the spring force is still optimally high at toe-off. Also, by using hinged, multiple bows, the spring deflection can easily be as large and optimal as is needed. Finally, perpendicular-spring/hinged-brace-foot assembly 27 can support sufficient torque for this application without need for a telescoping-tube guide system.

Figure 5c shows a side view of tibia perpendicular-spring/rigid-brace-foot assembly 29 which differs from the design of Figures 5a and 5b in that brace-foot end-plate 11 is now rigidly attached to brace foot 8. The intention here is to reap the benefits of a long brace foot, but this means that the pitch torque (in the front-back-vertical plane) must be resisted by the prosthesis. The shape of rigid-foot curved bottom 33 is designed to minimize this torque. The design benefits then are that the landing and take-off angles of the runner's leg are optimized, but these benefits must be traded off with the tolerable pitch torque. For the running aid application, brace foot 8 is even more important -- to match the length asymmetry of a running brace to the natural length asymmetry of the runner's leg/foot system which results from the greater length of the toe-to-hip-joint distance at toe-off than the length of the heel-to-hip-joint distance at heel-down. Again, the design goal of length asymmetry for the running aid and the specific asymmetry achieved depend on the precise shape of the bottom of brace foot 8. The length of brace foot 8 controls the amount of length asymmetry and the precise shape controls the rate (which should be steady) of forward motion of the effective contact point rate, i.e., the point around which there is no net torque due to the foot force -- between the ground and the bottom of brace foot 8. That is at toe-off, brace forefoot curved bottom 21 acts as a rolling pivot to limit the pitch torque on running aid 2 in Figure 1. The design of the shape of brace foot 8 to achieve length asymmetry and to optimize performance during the rollover from heel to toe is referred to herein as the weight transfer structure.

Figure 6 is a side view of running aid 2 from Figure 1 according to the second embodiment of the invention; Figure 7 is a front view of the same. Here, the bow is

decouple from the support. Only one side of brace leg 9 is shown in each figure, and harness center line 136 indicates the center of harness 3 in Figure 7. Running brace harness 3 shown in Figure 1 is not shown in Figure 6, but it is attached to hip-pivot rim 26 in the actual invention. Runner 1 is shown in Figure 6 as a dashed line.

Hip link 112 is rotatably attached to harness 3 via hip pivot 28 mounted in hip-pivot block 116. There are three senses of rotation for pivots, with respect to runner 1. "Pitch" refers to rotation about the side-to-side axis, "roll" - rotation about the front-to-back axis, and "yaw" - rotation about the vertical axis. Hip pivot cannot allow roll because of self-locking knee mechanism 121, to be discussed below. Hip pivot 28 must allow pitch so that the runner's leg can swing back and forth, and it may optionally allow roll to allow knee turn-out -- for runner 1 to change direction. Hip link 112 is a support member, and it serves to house bucky-bow spring mechanism 10 and to slidingly connect with thigh link 4 which slides along bearings within or beside hip link 112. Bucky-bow spring mechanism 10 comprises pulley block 104 to which are mounted inner pulley 106 and outer pulley 108 (rigidly attached to inner pulley 106). It further comprises bow spring 100 and bow strings 102 which extend from either end of bow spring 100 around inner pulley 106. Draw strings 103 then extend around outer 108 to be caught by spring catch 118 upon impact, as thigh link 4 is forced upward through hip link 112. Bucky-bow spring mechanism 10 further comprises thigh-link constraint 120 which allows bow spring 100 to bow, but which constrains the center of bow spring 100 to move straight down hip link 112.

The function of bucky-bow spring mechanism 10 is to allow bow spring 100 to absorb the runner's impact energy as thigh link 4 slides up through hip link 112, catching drawstring 103. Drawstring 103 then turns outer pulley 108 which turns inner pulley 106, pulling the ends of bow spring 100 together. The mechanical advantage achieved with this double pulley system allows a greater travel of draw string 103, and, hence, of bucky-bow spring mechanism 10, for a given flexing of bow spring 100. This allows a more lightweight bow for a given strength. For example, a bow spring 30 inches long and between one and two lbs in weight can give a constant force of 400 lbs with a draw-string 103 travel of six inches (same as the human center-of-mass travel). The use of pulleys also permits the possibility of changing the stiffness of spring assembly 5, which is analogous to changing gears on a bicycle. This change can be done simply with a conventional gear mechanism – to change the load-carrying pulley strings from one pulley to another. Finally, bow spring 100 can be inverted and attached to thigh link 4, so that hip link 112 pulls down on draw string 103, but it is preferable to have the weight of the lower brace

support on hip link 112.

In order for spring assembly 5 to carry out this function of bow-loading, self-locking knee mechanism 121 must be locked. That is, tibia link 7 must be loaded so that it exerts clockwise torque about knee pivot 6, causing thigh-link constraint 120 to impinge against tibia-link constraint 122 - in which case self-locking knee mechanism 121 is self-locked. Looking now at brace foot 8, tibia link 7 transmits the impact load to the ground via its rotatable (pitch) connection with knee pivot 6 on the top and its rigid attachment to brace foot 8. Heel pivot 130 connects brace foot 8 to the runner's foot behind her heel guaranteeing the release of self-locking knee mechanism 121, to be discussed with Figure 9.

Figure 8a is a side view of gas spring 30 with gas reservoir 34 which is the third embodiment of the invention. This combination can be used to achieve a substantially constant spring force curve. This substantially constant force curve is achieved by pre-pressurizing the gas to get a high initial pressure or spring force and a low force-curve slope as gas spring 46 deflects. A working definition of a constant force curve is that the average force over the range of deflection is greater than 70% of the maximum value during that deflection. For example, if a force curve is linear, the average force is 50% of the maximum. Increasing the pre-pressure (unloaded) value and the reservoir volume results in an increase of this average force value with respect to the maximum force value, but there must be a trade-off with weight. The running impact force compresses gas spring 30 as chamber cylinder 40 slides down around piston 38.
Gas line 32 transmits the pressure to gas reservoir 34 located above hip pivot rim 26. A single gas reservoir 34 can be used for both gas springs on both legs. The preferred gas in gas springs 30 is air, but it may be another gas.

Figure 8b is a schematic side view of gas pump 36 for replenishing lost gas in pressurized gas spring 30. Gas pump 36 is mounted next to gas spring 30 so that, when gas spring 30 is compressed, the gas pressure in pressure chamber 56 increases as pump piston 46 and gas seal 48 are pushed down by piston shaft 50. When the pressure in pressure chamber 56 exceeds the pressure in gas spring 30 to which it is connected via feeder tube 60, gas leaks through check valve 52 into gas spring 30. If the pressure there gets too high, pressure release valve 54 releases the pressure. On the return stroke, inlet hole 58 allows gas into pressure chamber 56 for the next pressure stroke.

Figure 9 is a side view of the support part of self-locking knee mechanism 121 of the running aid according to the fourth embodiment of the invention. It simplifies the picture of how this self-locking is achieved by showing only the

components needed for this demonstration. The purpose of self-locking knee mechanism 121 is to ensure that the support elements, thigh-link assembly 4 and tibia link 7 are locked straight during stance phase and free to bend about knee pivot 6 during swing phase. As the runner's leg extends before foot strike, these support elements approach the straight orientation shown Figure 9a, from the folded orientation shown in Figure 9b.

Self-locking knee mechanism 121 is shown in Figure 9c, and its purpose is to ensure that thigh-link constraint 120 and tibia-link constraint 122 close completely before foot strike for the self-locking to occur. This closing can also be referred to as the hyper-extension force. Posts 146 are rigidly attached to tibia link 7 and thigh link 4; center post 150 is rigidly attached to knee-pivot block 152. Knee spring 148 is attached to posts 146 and passes over center post 150, it acts to close thigh-link constraint 120 and tibia-link constraint 122 completely, and it is strong enough to ensure this closing, but weak enough to allow the runner's lifting leg to fold knee pivot 6 at toe-off. Note that by shortening posts 146 and/or center post 150 it is possible to reduce the hyper-extension force to any desired value after the knee pivot has folded beyond a particular angle, thereby reducing the force that the runner must exert in high kick.

At heel-down, the heel portion of aid foot 8 strikes the ground at the location of heel arrow 143, and heel centerline 142 indicates the line of force between hip pivot 28 and the ground. Since heel centerline 142 passes to the left of knee pivot 6, this impact force pushes thigh-link constraint 120 and tibia-link constraint 122 together, and self-locking knee mechanism 121 remains locked. As aid foot 8 rolls over forward until toe-off from the location of toe arrow 145, the force curve indicated by toe centerline 144 still passes to the left of knee pivot 6, and knee pivot 6 remains locked. Immediately at toe-off, the runner lifts her foot which is rotatably connected to heel pivot 130, at which time the force curve passes to the right of knee pivot 6, as indicated by foot-coupling pivot center line 140 -- between foot-coupling pivot arrow 141 and hip pivot 28 -- causing tibia link 7 to fold about knee pivot 6 as seen Figure 9b. The advantage of self-locking knee mechanism 121 is that it circumvents the problem of a knee-pivot lock, which is a very difficult problem because of the weight and strength constraints in view of the large torques involved. This self-locking can also be achieved with a foot-aid coupling in front of the runner's foot, but this approach is not as convenient. Also, the device can be prevented from locking at all by walking on very bent knees, e.g., up a steep hill or up stairs, or a mechanical switch can be incorporated into self-locking knee mechanism 121 to prevent thigh-link constraint 120 from approaching close enough

to tibia-link constraint 122 for the self-locking to take effect, thereby allowing the runner to walk or climb a steep hill.

Figure 10 is a side view of 4-bar foot–lift assembly 85 for maintaining clearance of aid foot 4 above the ground during swing phase. Foot-lift link 86 hingeably connects the front of aid foot 8 via toe pivot 88 to thigh-link extension 87 via foot-lift pivot 89. Thigh-link extension 87 extends rigidly from thigh link 4. When knee pivot 6 folds, thigh-link extension 87 lifts aid foot 8 via foot-lift link 86, thereby preventing aid foot 8 from dropping below the runner's foot and tripping him. Figures 10a, 10b and 10c display 4-bar foot–lift assembly 85 at various degrees of folding and straightening. Figure 10a shows that both foot-lift pivot 89 and knee pivot 6 have straightened to hyper-extend and lock against foot-pivot constraints 91 and tibia-link constraint 122 and thigh-link constraint 120, thereby ensuring that both foot-lift link 86 and tibia link 7 transmit the running impact load to aid foot 8. And, when heel pivot 130 lifts aid foot 8 and releases the locking of both foot-lift pivot 89 and knee pivot 6, the runner can high kick his foot behind him. Figure 10d shows thigh link 4 and thigh-link extension 87 as a single rigid element. Both foot-lift pivot 89 and knee pivot 6 require closing mechanisms (not shown here for clarity) to ensure that they close at heel down, such as the spring system shown with self-locking knee mechanism 121 in Figure 9c.

Figure 11 is a front cross-sectional view of variable-angle knee lock 61 which is a more versatile and sophisticated alternative to self-locking knee mechanism 121 of Figure 9 and which is the fifth embodiment of the invention. The idea behind this device is to make a shaft/collar system which turns freely when loaded on one side and which locks very strongly when loaded on the other side. By interleaving a number of strips, alternating between strips attached to the shaft and strips attached to the collar, it is possible to magnify the friction force by the number of interfaces between alternating strips. This means that a very large lock force can easily be achieved with a number, perhaps five or ten, of very thin, light, cheap metal circumferential strips 78. Also, the goal of this design is to load the lock radially rather than axially -- as is done with conventional car disk brakes. This radial loading eliminates the need for a force re-direction mechanism.

Figure 11a shows hollow shaft 62 (optionally hollow) and split collar 69 assembled together. The top portion of hollow shaft 62 and upper collar 70 form a cylindrical bearing surface so that when hollow shaft 62 pushes up against upper collar 70, they rotate freely. Figure 11c shows shaft boss 64 which is attached to the lower portion of hollow shaft 62 by boss screws 67. Boss spacers 68 interleaf with circumferential strips 78 – all of which extend circumferentially around the

bottom portion of hollow shaft 62. This circumferential extension can been seen in Figure 12 which is a side view of variable-angle knee lock 61. Boss screws 67 tighten boss stack plate 77 against boss spacers 68 interleaved with circumferential strips 78 and against shaft boss 64. Thus, circumferential strips 78 are fixedly attached to hollow shaft 62.

Figure 11b shows lower collar 71 with circumferential strips 78 – both of which are attached to shaft boss 64 by boss screw 67. The attachment of circumferential strips 78 to lower collar 71 is accomplished in a similar manner to their attachment to hollow shaft 62. Collar screws 73 tighten collar stack plate 66 against collar spacers 79 interleaved with circumferential strips 78 and against lower collar 71.

Figure 11a shows in assembly that alternating circumferential strips 78 attached to shaft boss 64 and lower collar 71 interleaf between each other. Thus, when lower collar pushes up against hollow shaft 62, a friction force is exerted between these alternating circumferential strips 78 attached to shaft boss 64 and lower collar 71. Specifically, this upward pushing causes the portion of lower collar 71 radially external to the interleaf region to compress the stack of interleaved circumferential strips 78 against shaft boss 64, thereby locking hollow shaft 62 from rotating in lower collar 71. The radial dimensions of collar recess 74 and shaft boss 64 are chosen to ensure that this compression and locking is unimpeded. Again, the frictional force of this device is proportional to the number of circumferential strips 78 and can easily be magnified to a very large value.

The circumferential ranges of extension of lower collar 71 and shaft boss 64 can been seen in Figure 12 which is an assembly side view of variable-angle knee lock 61 and in Figure 13 which shows the shaft and collar components separately. This particular choice of angular ranges gives a locking range of over 70 degrees which is more than adequate for the range of bent-knee angles needed for natural running, as can be seen in Figures 14a and 14b which show the rotation of lower collar 71 around shaft 62. Lower collar 71 is fixedly attached to tibia shaft 7, and shaft 62 is fixedly attached to thigh link 4. Again, the upward force of lower collar 71 on shaft 62 will cause locking over the range of tibia 7 rotation shown in Figure 14. Since thigh link 4 and tibia link 7 are approaching being aligned whenever foot impact occurs, it is likely that the jarring force transmitted up tibia link 7 to lower collar 71 will be sufficient to lock variable-angle knee lock 61, as is the case with prior-art, above-the-knee prostheses. If more force is needed, a foot-contact trigger can be used to initiate the locking of variable-angle knee lock 61. For example, a "brake cable" could transmit foot-impact force to close split-collar 69 by having

collar attachments 75 provide a sliding connection between lower collar 71 and upper collar 70 rather than a fixed attachment provided by collar attachment 75. It should be understood that if the bearing surfaces are located on the bottom side rather than the top side, thigh link 4 can be attached to split collar 69 and tibia link 7 to hollow shaft 62. Finally, variable-angle knee lock 61 allows uphill running, and it results in an effective gear changing because the spring action is not as aligned with the thrust action when variable-angle knee lock 61 locks at a more bent position.

Figure 15 is a side view of variable-angle knee lock 61 showing damper 82 for use with variable-angle knee lock 61. When tibia link 7 swings forward just before heel strike, it is important to prevent it from over-hyper-extending and from bouncing back off a stop. This is accomplished with damper 82 fixedly attached to damper arm 80 fixedly attached to thigh link 4. Figure 15b shows tibia link 7 swinging forward in the direction indicated by arrow 84 and approaching the straight-leg position. Figure 15 a shows that damper 82 absorbs the momentum of tibia 7 and stops it near the straight position. It should be understood that variable-angle knee lock 61 can optionally utilize a device to ensure that it opens to a straight orientation at heel-strike such as that shown in Figure 9c. Also, since variable-angle knee lock 61 locks over a range of angles, a simple damper such as a foam, gel or bladder can be used. This is an advantage over conventional knee locks used in above-the-knee prostheses which use expensive and sophisticated hydraulic mechanisms to prevent bounce back over a range of gaits. And, it should be understood that variable-angle knee lock 61 has applications in robots and above-the-knee prostheses. Also, there are other ways obvious to one of ordinary skill in the machining and fabrication arts to construct variable-angle knee lock 61– that do not depart from the device intent to radially load interleaving strips so as to magnify considerably the pivot lock force.

Figure 16 is a side view of 4-bar foot–lift assembly 85 showing tibia lock-release 93 for use with variable-angle knee lock 61. The purpose is to ensure knee-lock release at toe-off as was done in the example of self-locking knee mechanism 121 shown in Figure 9. In this case the hyper-extended, constrained pivot lock is located near the middle of what was tibia link 7 in earlier figures. The 4-bar foot–lift assembly 85 is the same as that shown in Figure 10, but now tibia-link 7 comprises lower tibia-link 96, tibia pivot 92 and upper tibia-link 94. The ends of upper tibia-link 94 and lower tibia-link 96 connected to tibia pivot 92 have double constraints 90 which serve to lock tibia pivot 92 on the hyper-extending side and to limit the folding of tibia pivot 92 on the other side. The lifting of aid foot 8 by the runner's foot via heel-pivot 130 breaks the hyper-extended locking action of both

tibia pivot 92 and foot-lift pivot 89 as shown in Figure 16b. Figure 16c shows a blow-up of the components of tibia lock release 93.

Figure 17 is a back view of cable system 200 which allows the use of single bow spring 202 in the sixth embodiment of the running aid invention. That is, one bow, located behind the runner's back, is used for either leg instead of two (one on each leg) as shown in Figure 6. This embodiment requires a system of pulleys to direct the force of single bow spring 202 to the runner's sides. For clarity, only the pulleys are shown, and the support attachments of the various pulleys are mentioned in this specification. Thigh link 4 transmits the impact force by pulling upward with pulley catch 118 on pulley cable 210 which passes around side pulley 205 (rotatably mounted to thigh link 4; mounting not shown). Pulley cable 210 next transmits the force back to back-pulley 206, mounted on back support 208, and then up to up-pulley 204, also mounted to back support 208. Actually, side pulley 205 will be directly in front of back pulley 206, but they are shown slightly offset here for clarity. Next, the force is transmitted to outer pulley 108 and to inner pulley 106, which are mounted behind the runner to back support 208, which is rigidly attached to hip pivot rim 26. Single bow spring 202 is connected to and interacts with outer pulley 108 in a manner similar to that shown with bow spring 100 in Figure 6, the difference being that single bow spring 202 can absorb impact force from the brace elements on either or both sides.

Figure 18 shows full harness 300 for the running aid with the front view on the left and the side view on the right. In the front view, runner 1 is shown in dashed lines, and the coupling between runner 1 and full harness 300 is made via pelvic rim 26 from Figure 6. Full harness 300 can be subdivided into thigh harness 302, pelvic harness 304, waist harness 306, and chest harness 308, and each of these can be further subdivided into multiple cuffs 310. Later, a figure will show a means to take some of the brace load on the arms of runner 1, as well. Stays 312 are rigidly attached to pelvic rim 26 and extend upward and downward from it to support the elements of full harness 300 via cords 314. Only the portion of pelvic rim 26 at either side is shown for clarity, but it encircles runner 1. Only those stays 312 on either side are shown for clarity, but there may be multiple stays around pelvic rim 26. Cords 314 can independently support each cuff to better distribute the brace load along the length of full harness 300, and there may be one or more cuffs 310 in each harness subdivision. Finally, only a portion of the full harness 300 shown may be needed and used in this invention.

One very important feature of this extensive harness is that the harness portions which support and upward pull can be tightened down against the harness

portions which support a downward pull. For example in Figure 18, waist harness 306 can be cinched down to thigh harness 302 with straps, and vice versa. This allows the compliance of the underlying runner's flesh to shear to be reduced substantially.

It may be possible to comfortably support a runner with harnesses that are simply tight and extensive, but the following discussion gives designs for harness in which the load of the runner on the running brace tightens the harness. This load-tightening feature may be used with a portion or all of full harness 300. The advantages are (1) that the harness tightens as the load increases, thereby increasing its load capability and (2) the harness loosens when not loaded, thereby improving blood circulation and comfort for the runner.

Figure 19 is a side schematic view of a generic mechanical design for mechanical load-tightener cuff 322 used in full harness 300 for the running aid. In the bottom section of Figure 19, load-tightening cuffs 320 overlap and in the top section they do not. Looking at the top section, the two ends of load-tightening cuffs 320, which encircle a portion of the runner's body part, are attached to adjacent cuff buckles 328, which, in turn, are attached to mechanical load tightener 322 via tightening cords 324. When the brace load pulls up on mechanical load tightener 322 as indicated by load arrow 330, mechanical load tightener 322 causes tightening cords 324 to pull inward as indicated by tightening arrows 330, thereby tightening load-tightening cuffs 320. Referring to the bottom section of Figure 19, the same tightening occurs. The difference is that mechanical load tightener 322 must be wide enough to pull together either side of load-tightening cuffs 320 which now overlap by virtue of ending with cuff fingers 334. The advantage of this overlapping is that the surface of load-tightening cuffs 320 is smooth in the vicinity of mechanical load tightener 322, thereby providing greater comfort to the runner. In the following examples of load-tightening designs, only one will show this overlapping, but it should be understood that any of them can be adapted for overlapping.

Regarding the use of load-tightening cuffs 320 in general, these may comprise means for lacing or cinching to achieve a snug yet comfortable degree of pre-tightening. Further pre-tightening may be achieved by tightening different levels of the harness, one against the other. For example, waist harness 306 may be cinched down against pelvic harness 304 to reduce the compliance between the runner's flesh and the harness. Depending on how much soft tissue there is below the runner's skin, the skin may move a half-inch to an inch or more under shear. Pre-tightening can eliminate most of this compliance.

Figure 20 shows examples of compressible woven harness 340 for load-tightening sleeves of the harness for the running aid. On the left side thigh harness 302 and torso harness 344 are held at either end by hoops 342. Braids 346 are interwoven about the shape of a pelvis and thigh. Provided their lower sections are sufficiently anchored, when the upper hoop 342 pulls upward, compressible woven harness 340 must shrink or compress, and this results in gripping of the underlying object, in this case the runner's body parts. In order for this gripping to occur, the individual braid material which composes compressible woven harness 340 must be inelastic to stretching, but flexible to bending over the shape of the underlying object. This idea is similar to that used for the finger traps known as Chinese hand cuffs, in which a number of bands (tapes, ribbons, strips) are inter-woven into a tube which traps the fingers of unwary children. On the right side of Figure 20 compressible woven harness 340 is composed of braids 346 in such a manner that there is substantial void space between braids 346. This has several advantages: ventilation for the runner, a greater compression range, and improved traction of braids on the compressible human flesh underneath. The relative amount of contraction for a given extension between hoops 342 depends on the number, width, thickness and pitch angle of braids 346, as well as on their friction coefficient with the underlying surface. If the underlying surface is irregular, it can also be seen that judicious locations of stays 312 and cords 314 in Figure 8 can improve the even distribution of load along the length of a harness.

An important feature of the woven mesh design is that the bottom portion of the sleeve must be sufficiently well anchored as to cause the higher regions to contract and thereby distribute the (upward) load up the entire sleeve length. This may be accomplished for thigh sleeve 20 with straps extending down and around the foot or with straps extending to a cuff around the runner's tibia below the knee. Or, since the runner's thigh has a natural taper, keeping the lower portion of thigh sleeve 20 fairly tight may be sufficient in some cases to achieve this anchoring. Once sufficient bottom anchoring is achieved, the load is distributed up the length of compressible woven harness 340, which is the overall goal.

Figure 21 is a side view of overlap double-pulley load tightener 318 which is an example of a mechanical load-tightener 322 used in the harness for the running aid. The discussion here is similar to the discussion of mechanical load-tightener 322 for Figure 9 except that mechanical load tightener 322 is shown in detail rather than schematically. Mechanical load-tightener 322 comprises load-tightening cuff 320 attached on either end to cuff buckles 328 and overlapping each other via cuff fingers 334. It further comprises spreader bar 323 which is mounted to load-

tightening cuff 320 at spreader bar tab 325 and which has rotatably mounted on either end tightening pulleys 336. When the brace load pulls up on stay cords 326 at indicated by load arrows 332, stay cords 326 pass around tightening pulleys 336 to pull tightening cords 324 as indicated by tightening arrows 330, via cuff buckles 328, thereby tightening load-tightening cuffs 320. Spreader bar 323 is anchored below via anchor cords 327 as indicated by anchor arrows 329. At first, it may seem self-defeating to require additional anchor cords for spreader bar 323 because the goal is to be able to pull up on load-tightening cuffs 320 with the brace load via stay cords 326 and the attachment to spreader bar 323 at spreader bar tab 325. If load-tightening cuffs 320 are already tight enough, anchor cords 327 are not needed, but they provide back-up as the tightening begins. The top section of Figure 21 shows a blow-up of tightening pulley 336 which optionally may comprise inner tightening pulley 338 and outer tightening pulley 339. In this case, there is a mechanical advantage whereby the travel of stay cord 326 is augmented by a factor equal to the mechanical advantage between these pulleys to create a greater travel of tightening cord 324. This is an important feature because it reduces the slack or compliance needed to tighten mechanical load-tightener 322. This means that the running aid can give substantial support to the runner quicker, and this is key to natural running.

Figure 22 is a side view of bent-lever load tightener 350, jamming load tightener 352, and inward-force load tightener 375 of the harness for the running aid. These are examples of the mechanical load tighteners 322 shown in Figure 9 and Figure 21, and the first two function in a similar manner. Bent-lever load tightener 350 is shown in the bottom left of Figure 22. Bent levers 356 are rotatably attached to spreader bar 323 which is attached to load-tightening cuff 320 via cuff hoop 354. Cuff hoop 354 is slidingly attached to load-tightening cuff 320 so as to not impede its tightening. Provided load-tightening cuff 320 is well pre-tightened or provided spreader bar 323 is well anchored below, when stay cord 326 pulls up (see load arrow 332) the top arms of bent levers 356, then the bottom arms of bent levers 356 pull the ends of load-tightening cuff 320 inward via cuff buckles 328 (see tightening arrows 330). A similar function occurs for jamming load tightener 352 in the top left of Figure 22. Here, as spreader bar 323 is pulled up, jamming links 358 tighten load-tightening cuff 320. It should be understood that cuff hoop 354 can be used with any of the cuffs discussed herein, and it may be segmented or telescoping to allow cuff 20 tighten. Inward-force load tightener 375 is shown on the right of Figure 22, and it functions slightly differently. Frame hoop 379 is rigidly attached to harness 3 of Figure 1 and encircles body part 378, and it is strong enough to be rigid

when the jamming links 358 on either side jam against pressure pads 376 on either side to grip body part 378 as a brace load force pushes up on frame hoop 379 – to clamp or grip body part 378 as it is supported. It should be understood that there may be a number of these elements distributed about the body harness, and there are a number of mechanisms known to one of ordinary skill in the art for accomplishing this gripping. Again, this last load-tightening mechanism is distinguished from the earlier ones by virtue of the fact that the clamping force is directed inward toward the body part instead of circumferentially around the part body tightening a cuff.

Figure 23 is a side view of combination mechanical/ weave load-tightener 360 of the harness for the running aid. Its purpose is to lift and simultaneously apart spread compressible woven harness 340. Vertical spreader bar 364, attached to top hoop 370, pulls upward on compressible woven harness 340 -- attached at its top to top hoop 370 and its bottom to bottom hoop 372. This upward pull is exerted by cables 366 which pass from vertical spreader bar 364 around block pulleys 362, and then all the way down to pass around spreader pulleys 363 -- attached to the bottom of vertical spreader bar 364 – to finally pull down on bottom hoop 372, thereby spreading compressible woven harness 340 and causing it to contract and grip the underlying body part. Block pulleys 362 serve to equalize the upward force on top hoop 370 with the downward force on bottom hoop 372. Cable arrows 374 indicate the pull directions that achieve the spreading apart of compressible woven harness 340. This spreading causes a quicker gripping of the body part, which eventually is lifted when the gripping force becomes sufficiently large.

Figure 24 is a side view of arm load-bearing harness 380 for the running aid. Runner 1 and runner's arm 390 are shown as a dashed line. The lower running aid is not shown but is attached to pelvic rim 26 as is shown in earlier figures. Arms beam 392 is rigidly attached to pelvic rim 26, and swing links 384 are rotatably attached to arm beam 392 to support arm rest 388 which supports runner's arm 390 via arm pad 386. Accordingly, runner 1 can support a substantial portion of her weight on arm load-bearing harness 380 and still swing her arms.

Figure 25 shows a schematic front view of load-equalizer stay tree 400 which distributes the brace load over various parts of the harness for the running aid. On the left side of the figure stays 312 support cords 314 which attach to cuffs 310, which make up a body harness. In this case, the load will be distributed approximately evenly over each cord 314 and cuff 310. If one wishes to vary the load on a particular cuff 310, the elasticity of the attached cord 314 can be varied. In the event that one wishes to ascertain that there is an even load distribution without have to make all the cords 314 just the right length, load-equalizer stay tree

400 may be used. Here, cords 314 are attached at one end to the bottom of load-equalizer stay tree 400 and at the other end to the top cuff 310. In between, cord 314 passes over stay pulleys alternately attached to cuffs 314 and load-equalizer stay tree 400. The result is that load-equalizer stay tree 400 pulls up evenly on cuffs 310 via the attached pulleys. The detailed and workable design is more involved, but this figure demonstrates the principle.

Figure 26 shows adjustable harness 403 for the running aid. Adjustable bands 404 pass around a body part and through fitting clamps 406. When adjustable bands 404 are pulled to fit tight about the underlying body part, a portion – namely leftover bands 408 -- of their lengths stick out the other side of fitting clamps 406. In this way a range of sizes and shapes can be snugly fit with adjustable harness 403. The same device can be use to adjust braids 346 which make up compressible woven harness 340 in Figure 20. This adjustability is important because a self-tightening harness material should have minimal elasticity.

Figure 27 shows a side view of a generic brace leg with a circular brace foot 8, demonstrating graphically how well the brace foot prevents vertical travel of the runner's center of mass throughout stance. The figure depicts a stick leg, brace leg 9, running from left to right. The stick figure on the left shows heel-strike and on the right shows toe-off. The center sequence shows the trajectory of the top of brace leg 9 throughout stance, at 10 degree intervals of rotation - with alternating positions being either solid or dashed. In the first 10 degrees, the brace top rises 0.5" (for a 30" leg); for the next 30 degrees, the brace top stays level because the radius of brace foot 8 is also 30"; and for the last 10 degrees the brace top falls 0.5". The curved brace foot can be used with any of the embodiments for the running aid herein, or it can be used in the tenth embodiment with a straight rigid leg as shown in Figure 27. In this case the "running aid" is actually a walking brace used for support.

Figure 28 shows hyperlocker 500, a mechanism to guarantee hyper-extension of the self-locking knee mechanism of the fourth embodiment of the invention of Figure 9. Thigh link 4 rotates about hip pivot 28. Since the direction of running is from right to left on the page, the right side depicts the early stage of swing phase after toe-off. The left side depicts the instant just before heel-strike when knee pivot 6 is hyper extended. The purpose of hyperlocker 500 is to force hyper-extension before heel-strike, while still being able to freely fold knee pivot 6 at toe-off. This is done by keying hyperlocker 500 to the position of thigh link 4 - either swung forward or backward. When thigh link 4 swings forward (leftward), slide-pulley cord 526 pulls slidable thigh pulley 524 up, via top thigh pulley 520 against rim

beam 518. Closer cord 514 runs from closer-link attachment 510 around thigh-link pulley 512, up to slidable thigh pulley 524, back down to and through beam pulley 506 (on the end of upper closer beam 502, to end at cord ball 522. When thigh link 4 is swung back, slidable thigh pulley 524 slides down thigh link 4, and closer cord 514 has enough slack so as to allow closer links 508 to bend and knee pivot 6 to fold with no resistance from closer cord 514.

However, when thigh link 4 swings forward (leftward, in swing phase), slide-pulley cord 526 pulls slidable thigh pulley 524 up thereby pulling closer cord 514 taut. Now, when tibia link 7 starts to move down to prepare for heel-strike, closer-cord catch 516 on the end of lower closer beam 504 catches cord ball 522, causing closer-link attachment 510 to be pulled toward thigh-link pulley 512, causing the hyper-extension of tibia link 7 about knee pivot 6. By adjusting the various parameters, it is possible to choose the fold angle at which the hyper-extension action begins. Also, a spring can be incorporated in closer cord 514.

Figure 29 shows slider 530 for changing the length of a running aid according to the seventh embodiment of the invention. Slider 530 comprises middle guide 564 and inner guide 566 (which may be telescoping tubes) as well as slider ratchet 532. The purpose of slider 530 is to change the length of the running aid even when knee pivot 6 is hyper-extended, to allow uphill running. Slider 530 changes length freely during swing phase; at heel-strike, a foot-contact trigger, such as the one shown in Figure 30, engages slider ratchet 532 to lock slider 530 throughout stance. When the total brace length can be changed in two ways, with a slider and a knee pivot, it is important to ensure that the hyper-extension of the knee-lock occurs. Hyperlocker 500 of Figure 28 ensures this. Note that bow guide 110, comprising outer guide 562 and middle guide 564, significantly overlaps slider 530 -- allowing greater length for both elements.

Figure 30 shows full-stance brace-foot trigger 540 for locking slider 530 throughout stance. An array of ground levers 542 are rotatably attached to curved brace foot 8 along its length. The tops of these are fixably interconnected by ground trigger cord 546, each of which pulls ground trigger cord 546 around ground pulley 544 and down the length of tibia length 7, when that ground lever 542 is caused to rotate by contact with running surface 37. This is true at heel-strike, shown on the right side of the figure, until toe-off, on the left side of the figure. That is, even though each particular ground lever is not always in contact with running surface 37, there is always at least one ground lever 542 in ground contact. Since all ground levers 542 are interconnected at their tops, it only takes one ground lever 542 to pull on ground trigger cord 546, ensuring that the force engaging slider ratchet 532 of

Figure 29 is exerted throughout stance.

Figure 31 shows foot-coupling guaranteed release mechanism 548 for release of slider ratchet 532 of Figure 29 at toe-off. This can be used in place of the hyper-extended knee locks of Figures 9, 10, and 29 to prevent a knee lock or a slider lock from sticking due to premature lifting of his foot by a runner. Foot pivot square extension 552 extends from the shaft used for pivotable coupling between a runner's foot and brace foot 8. The idea is for foot pivot square extension 552 to freely move up within down-spring slot 549 just at toe-off, thereby reducing any upward force exerted by the runner's foot on the brace foot for an instant, allowing any slider lock to release. During swing phase, foot pivot square extension 552 must be returned to the bottom of down-spring slot 552 to prevent brace foot 8 from hanging below the runner's foot and tripping him. This return to the bottom is accomplished with a spring cocked by the force of heel-strike and then released by the upward motion of foot pivot square extension 548.

In detail, Figure 31a depicts the mechanism during stance. Ground lever 542 is rotated by ground contact to hold down foot pivot square extension 552. Down spring 554 is cocked and held in place by down-spring pawl 556. Down spring 554 was cocked by the rotation of ground lever 542 at heel-strike, via the downward pull on cocking cord 560 which runs over cocking pulley 558 to pull up on down spring 554. Figure 31b depicts the instant just after toe-off. Ground lever 542 is pulled upward by ground-lever return spring 550 releasing foot pivot square extension 552 to be lifted by the runner's foot, (This is when foot pivot square extension 552 freely moves up within down-spring slot 549; this free motion allows slider ratchet 532 of Figure 29 to release.) pushing down-spring pawl 556 to the side until it releases down spring 544 which pushes foot pivot square extension 552 back to the bottom of down-spring slot 549 (as shown in Figure 31c) where it stays until heel-strike. Figure 31d shows the beginning of heel-strike. Ground lever 542 is being rotated to pull down cocking cord 560 to pull up and cock down spring 554 as it is pulled high enough for spring-loaded down-spring pawl 556 to rotate and catch it -- at which time Figure 31a applies again.

Figure 32 shows simple-slider running aid 561 according to the eighth embodiment of the invention, wherein a knee pivot is no longer used. The elements of slider 530 and bow guide 100 have been explained in the discussion of figure 29. Instead of having a knee pivot connect to a tibia link below bow guide 100, inner guide 566 extends straight down, all the way to brace foot 8. This embodiment is simple in that it eliminates the knee pivot and all the related mechanisms, but its drawback is that it is not possible to high-kick as high. Full-stance ground trigger

540 of Figure 30 and foot-coupling guaranteed release mechanism 548 of Figure 31 can be incorporated in this embodiment. It is possible that the spring which causes slider ratchet to pull away from and disengage from inner guide 566 can be strong enough to guarantee slider lock release in which case foot-coupling guaranteed release mechanism 548 would not be needed. The top of outer guide 562 would be attached to hip pivot 28 in a manner similar to that shown in Figure 6.

On the right side of Figure 32 there is shown retractable brace foot 545 with lockable hinged extensions 547 which can be locked for running or walking on relatively flat or shallow sloping terrain and which can be retracted for running or walking on steps or steep terrain.

Figure 33 shows a means to combine an active power source with a passive spring according to the ninth embodiment of the invention. In this case actuator piston 44 is propelled downward within actuator housing 43 during the active power stroke. This results in an upward force on actuator housing 43 and on bow guide 110 which compresses bow spring 100. Even if the power stroke is of very short duration, the timing of the expansion of bow spring will be slow enough to appropriately couple with the runner's weight at the top of bow guide 110. In effect, the active component extends the power stroke delivered by the bow spring, and the timing problem is solved by putting the active component in series with the passive component.

Figure 34a shows booted lockable hydraulic slider 571 and Figure 34b shows nested lockable hydraulic slider 594 both of which can be used for the various lockable sliders. The idea is to utilize the resistance of flow of fluid through a valve to lock, unlock, or control the length change of the two brace length-change means discussed herein: namely, knee pivot 6 of Figure 1 and slider 530 of Figure 32. Referring to Figure 32a, booted lockable hydraulic slider 570 comprises hydraulic piston 576 which slides within hydraulic cylinder 575. Fluid flows between hydraulic chamber 578 and bladder boot 581 through top orifice 579, through fluid lines 586, and through the following valve system. Fluid line 586 branches to go through return check valve 580 (allowing fluid to return to hydraulic chamber 578) on one side and through exit valve 582 and exit check valve (allowing fluid to exit hydraulic chamber 578) on the other side.

Exit valve 582 is triggered (by release of toe contact using the full-stance ground trigger 540 of Figure 30) to open at toe-off – thereby allowing fluid 572 to move into reservoir 574 as hydraulic piston 576 moves up during the runner's high kick after toe-off. Since there is no resistance to this opening of exit valve 582, even if the runner's foot is prematurely lifting the brace foot, the release of lockable

hydraulic slider 570 is guaranteed.

In swing phase, hydraulic piston 576 is now free to move both up and down as one check valve allows fluid to flow in and the other allows fluid to flow out. Just before heel-strike, exit valve 582 is triggered (by pre-strike heel contact) to close. At heel-strike, hydraulic piston 576 cannot move up because exit valve 582 is closed. Thus, lockable hydraulic slider 570 is locked. In view of the fact that some running brace designs require hydraulic sliders to resist considerable non-axial loads, piston sliding friction is reduced by not using o-rings. This is possible since bladder boot 581 receives any fluid that leaks through the small area between hydraulic piston 576 and hydraulic cylinder 575; bladder boot 581 is sealed by ring seals 583.

Cylinder rollers 585 resist any non-axial load in any design application where hydraulic piston 576 slides under load. For example, in order to walk down steps or to run downhill, exit valve 582 can be controlled to be partially open, allowing 576 hydraulic piston to move slowly upward and lockable hydraulic slider 570 to slowly compress. The size of the opening of exit valve 582 determines how fast the runner or walker can walk down steps, and the valve can be controlled manually by the runner.

Figure 34b shows that one telescoping element can be nested within another to achieve a higher "high-kick" by the runner just after toe-off. Also, conventional o-rings are used to prevent fluid leakage for this case where the bladder reservoir is not booted. Nested lockable hydraulic slider 594 further comprises inner piston 588 which telescopes within hydraulic piston 576, which now has a hole, fluid opening 590, to allow fluid to flow from inner hydraulic chamber 592 through hydraulic chamber 578 to reservoir 574. The timing of the triggering is the same as that just discussed.

Again, nested lockable hydraulic slider 594 and booted lockable hydraulic slider 571 can be simply substituted for the sliders discussed elsewhere herein, or it can be used to lock a knee pivot. Figure 35 shows knee pivot 6 locked by lockable hydraulic slider 570 according to the eleventh embodiment of the invention. The triggering is the same as that just discussed. When booted lockable hydraulic slider 571 locks, knee pivot 6 also locks.

Figure 36 shows self-hyper-locker 36 for guaranteeing hyper-extension at foot strike. The idea is to route closer cord B 624 around a path which passes both on the front side and back side of folding knee pivot 6 in such a manner that the back part of the path (between top inside post 604 and inside pulley 628) increases faster than the front part of the path (between top outside post 602 and outside pulley 626)

as tibia link 7 and thigh link 4 unfold about knee pivot 6. By choosing a certain length of closer cord B 624, closer cord B 624 becomes taut at a particular flexion angle as the unfolding occurs, causing closer cord B 624 to begin to pull on closing spring 610 which acts to accelerate the unfolding, especially if closing spring 610 is pre-loaded (which is easily accomplished with a plug (not shown) on closer cord B 624 just below the bottom of notched tube 608). Top outside post 602 and top inside post 604 are fixably attached to thigh link 4. Bottom outside post 630 and bottom inside post 632 are fixably attached to tibia link 7 – providing support for outside pulley 626 and inside pulley 628. Notched tube 608 is attached to top outside post 602 by reset spring 620. Closer cord B 624 is attached to notched tube 608 via closing spring 610 which is stronger than reset spring 620. Notched tube 608 is slidably connected to thigh link 4 via notched-tube guide 606. Pawl 612 is pivotly connected to thigh link 4 at pawl pivot 616 via pawl tab 614 (fixably attached to thigh link 4). Pawl spring 618 bias pawl 612 to engage the notch in notched tube 608 when it is pulled upward in swing phase by reset spring 620.

Accordingly, Figure 36a shows self-hyperlocker 600 in swing phase when closer cord B 624 is slack and there is no unfolding force -- allowing the tibia link 7 to swing freely. Reset spring 620 has pulled notched tube 608 up so that pawl 612 can engage its notch. Again, at a particular flexion angle closing spring 610 slams tibia link 7 closed as seen in Figure 36b. Just after the joint becomes hyper-extended, pawl bumper 622 impinges the bottom of pawl 612 causing it to disengage from the notch of notched tube 608, thereby releasing closing spring 610 from its folding force because notched tube 608 moves down notched-tube guide 606 - shortening the patch of closer cord B 624 (shown in Figure 36c) and causing it to become slack. Thus, there is no closing force later, at toe-off, to resist folding and high kick. Self-hyperlocker 600 is called "self" because it does not require any trigger from the foot or the hip to work. The release of closing force is keyed to hyper-extension at the knee pivot. Self-hyperlocker 600 can be used with simple-hinge knee pivots or with four-bar knee pivots (in which case it only needs to be located at one of the two knee pivots).

Figure 37 shows a "hyper-extension bounce back" prevention means for prevention of folding of a hyper-extending knee lock at heel strike. Pinched bladder 640 is glued to bladder step 646 in tibia link 7. Pinch band 624 forms a portion of pinched bladder 640 exterior to bladder step 646. And it allows only a small orifice connecting the main body of pinched bladder 640 with elastomer nipple 644. When tibia link 7 closes to the point where hyper-extension of the joint begins, the bottom of thigh link 4 squeezes bladder fluid through the orifice made by pinch band 642

into elastomer nipple 646, causing it to expand. The resistance to fluid flow through a small orifice absorbs the impact energy of the closing of the joint so it does not bounce back open. The force exerted by the expansion of elastomer 644 is too small to re-open the joint when it is loaded by a runner's weight, but this force is large enough to force the fluid back through the orifice during swing phase when pinched bladder 640 is no longer squeezed. This is a very cheap and simple way to eliminate bounce-back opening of the knee joint as compared with elaborate, expensive hydraulic devices used in conventional above-knee prostheses.

Figure 38a shows a rear view and Figure 38b a side view of front/back brace leg 650 in which the pelvic coupling is made directly behind and in front of the runner's ischial tuberosity (buttock) rather on the side of the hip. Front hip pivot 678 is pivotly attached to harness 3 directly above runner's leg 676 in front, and back hip pivot 680 is pivotly attached to harness 3 directly above runner's leg 676 in back. Front and back -- hip pivots 678 and 680, knee pivots 660 and 662, and thigh links 652 and 654– and knee cross link 674 form a four-bar system. Front and back -- ankle pivots 670 and 672, knee pivots 660 and 662, and ankle links 670 and 672 – and knee cross link 674 form another four-bar system – with knee pivots 660 and 662 and knee cross link 674 being shared between these two four-bar systems. The runner's pelvis and/or harness 3 act as the cross link at the hip level for the upper four-bar system, and brace foot 8 acts as the cross link at the foot level for the lower four-bar system. These two four-bar systems are sufficiently distant from runner's leg 676 throughout a stride as to not interfere with the same. Back hydraulic knee lock 664 is rotatably connected to a back thigh link 654 and back tibia link 668 so that when a foot trigger (not shown, but straightforward to implement for one of ordinary skill in the art) locks back hydraulic knee lock 664 as foot strike, flexion about back knee pivot 662 is locked. Another knee lock could be used for front knee pivot 660, but this is not necessary because back knee pivot 662 is shared by both four-bar systems. That is, when back knee pivot 662 is locked, both the above-mentioned top and bottom four-bar systems are converted to three-bar systems, and both structures are locked. Folding of the upper and lower four-bar systems with respect to each other is realized as the runner's weight leans forward. This folding can be enhanced by tethering front and back knee pivots 660 and 662 to the runner's knee. The runner's foot can now be coupled to brace foot 8 anywhere along the length of the runner's foot. Front and back bows 656 and 658 store and return impact energy, and only one of these need be used. Finally, if the one or both knee pivots in Figure 38 are constrained from hyper-extending (see e.g. Figures 16 and 36), a separate knee lock, such as back hydraulic knee lock 664,

can be eliminated since the "constrained hyper-extension knee lock" naturally locks at heel-strike and naturally starts folding just before toe-off. Having a separate knee lock allows the runner to run uphill or to land with a more substantially pre-bent leg, but this capability is not needed in many applications. This is even more true for a running brace than for above-knee prostheses, since the runner's leg is there to prevent a fall.

Figure 39 shows front/back pack extension 690 for comfortable and optimal pack load support. The running/walking brace shown is front/back brace leg 650 of Figure 38. Front pack frame 692 is pivotly attached to the top front of front/back brace leg 650 by pack-frame pivot 698, and back pack frame 694 is pivotly attached to the top back of front/back brace leg 650 by pack-frame pivot 698. Pack straps 696 attach front pack 700 to front pack frame 692, and back pack 702 to back pack frame 694. If the brace legs were not supporting the pack weight, there would be an uncomfortably high load on the runner's shoulders. Also, the front parts of front/back pack extension 690 can be eliminated, in which case runner 1 must lean forward at the waist to balance the pack.

Figure 40 shows four-bar knee joint 704 with hyper-extension stop708 which prevents hyperextension of the joint. Optional four-bar hydraulic lock 706 can be used to lock four-bar knee joint 704 and which can be triggered to lock a foot-contact in a manner similar to that of booted lockable hydraulic slider 571 of Figure 34.

Figure 41 is a schematic side view of a low-eccentricity knee-joint straightener 720. It resists folding about side knee pivot 6 with only a very small force (of circle spring 728) beyond a chosen flexion angle so that the wearer is free to high kick. As tibia link 7 descends beyond this chosen flexion angle, low-eccentricity knee-joint straightener 720 acts to accelerate this straightening via close spring 724 with a force that increases proportional to eccentricity 712 of the spring force about knee pivot 6. Thus, the greatest straightening force acts when full straightening occurs. The components are assembled as follows. Circle tube 730 is rigidly attached to thigh link 4 and circle brace 732 which extends rigidly from thigh link 4. Slide ring 726 slides along circle tube 730 and it is connected both to close spring 724 which extends down to connect to tibia link 7 and to circle spring 728 which extends through circle rube to connect to its upper end. Slide ring 726 is constrained from sliding up and to the right at a chosen location. Pivot stops 86 prevent hyper-extension about side knee pivot 68. In Figure 41a, the configuration is straight, eccentricity 202 is at a maximum value, and the straightening force is at a maximum value. In Figure 41b, shin tube has folded to the point where shin-tube

extension 722 impinges slide ring 726, eccentricity 702 is very small, and the straightening force due to close spring 724 is very small. In Figure 41c, shin tube 64 has folded considerably. However, the straightening force due to close spring 724 is still very small because slide ring 726 is forced to slide around circle tube 730 by shin-tube extension 722 and eccentricity 702 remains very small. There is still a very small resistance to folding due to circle spring 730 which is much weaker than close spring 724. Again, as straightening progresses beyond the configuration of Figure 41b, the straightening force increases rapidly.

This completes the discussion of the figures. Now a few general issues will be discussed. One of the key problems discussed in various parts of this patent is to guarantee the release of the lock of the swing-phase length change means, which can be the self-locking knee mechanism Figure 9, the variable-angle knee lock of Figure 11, the slider of Figure 29, or the simple slider of Figure 32. This lock release is necessary but not sufficient for guaranteed folding (about the knee pivot for the hyper-extended knee locks) which will be discussed afterward. Guaranteed lock release is necessary because a runner can lift the brace foot prematurely, thereby preventing a break in the loading of the lock, therefore preventing lock release; then the runner could fall flat on her face. For the hyper-extending design of Figure 9, a simple spring between thigh-link constraint 120 and tibia-link constraint 122 might suffice. If more guarantee is needed the hyperlocker mechanisms of Figure 28 and 36 can be utilized. Also, a four-bar system such as that shown in Figure 38 will naturally fold as the runner's weight leans forward near the end of stance. For the variable-angle knee-lock, tibia lock-release 93 of Figure 16 can be used if a simple spring -- to push down split collar 69 with respect to hollow shaft 62, thereby disengaging circumferential strips 78 -- does not suffice to release the lock at toe-off. For the slider of Figure 29 or the simple slider of Figure 32, a spring to disengage slider ratchet 532 may be sufficient to release the lock at toe-off. If not, foot-coupling guaranteed release mechanism of Figure 31 can be used.

Guaranteed folding (about the knee pivot for the hyper-extended knee locks) is achieved with a heel coupling in Figure 9, a knee tether (mentioned in the discussion of Figure 38 although it could be used in any of the hyper-extended knee locks), and as a natural consequence of a forward lean in the discussion of Figure 38 of a four-bar knee pivot. It simply means that the force exerted by the runner on the

brace leg must fold the knee pivot rather than hyper-extend it.

In conclusion, the invention herein described comprises a variety of passive or spring running aids-- most notably an energy efficient running aid or brace which provides optimally fast support of a runner's impact load by virtue of the buckling load force curve of the bucky-bow spring and by virtue of the load-tightening body harness with minimal compliance. In addition, the designs can also be used for walking or in conjunction with an active power source. The spring is lightweight and features an optimally long travel, along with an optimal constant force curve. In the second embodiment of Figures 6 and 7, since a cable system with pulleys is used, there is a "gear changing" feature, and a single bow spring can be used for either leg. The harness achieves a unique capability in that it provides for a uniform distribution of impact load over a substantial portion of the runner's body, even though the runner's body is vertical. Comfort is enhanced with a load-tightening feature of the harness. The daunting knee-lock problem is circumvented with a knee self-locking device of Figure 9 which solves the other difficult problem of guaranteed knee-lock release, and it is solved with the variable-angle knee locking device of Figures 11-14 and the lock-release devices of Figures 16, 31, 34 and 36. This variable-angle device allows uphill running, and it results in an effective gear changing because the spring action is not as aligned with the thrust action when the knee pivot locks at a more bent position. Finally, a shaped brace foot solves the problem of leg-length asymmetry. The overall design is lightweight, and this aspect is improved by minimizing the distill weight of the running aid.

It should be understood that the running aid described herein has many features which apply to robotic running as well as to a running brace. These include the spring mechanisms for energy return, the brace foot, and the self-locking pivot. The running aid invention uses either the pulley-bow or the series bucky bow, as well as the single pulley bow in the back, all can be easily adapted to robotic running. The brace foot should be used as well in robotic running to optimize the angles of leg/foot support while landing and taking off for greater performance and fuel economy. A slight adaptation would be needed to use the self-locking knee pivot because there is no runner's foot to lift up the heel pivot to fold the knee pivot. Instead, a cable could be spring-loaded and triggered by toe-off to pull on the heel pivot to unlock the knee pivot for swing phase. And, the uphill running feature to allow the bow to engage and the knee pivot to lock when the runner's leg lands partially bent can also be use in robotic running. Also, the front/back brace leg of Figure 38 can be used for exo-skeleton applications which are active as well as passive. And, it can be used for above-knee prostheses and robots. Furthermore,

separate four-bar systems can be used to allow articulation in the roll plane as well as the pitch plane.

The running aid designs herein also can be used for both walking even though the main thrust in the development of these designs has been for running. These running aid designs can also be used for carrying a backpack. The backpack can simply be attached to the pelvic rim of the harness in which case the running aid substantially supports the load of the backpack, and the harness is not needed -- at least for support of the pack by the running brace. Or, as just described for Figure 39, the front/back brace leg of Figure 38 can be used to support pack weight both in front of and behind the runner via a front/back pack extension. This design provides for improved equilibrium of the runner/pack system, and it eliminates the uncomfortable backward force on the runner's shoulders resulting from pack which is only in the back.

Since the preferred spring systems described herein provide an approximately constant force curve, they also provide for the maximum amount of absorption and return of impact energy – given a threshold level of force that the human body can safely tolerate. This means that these preferred spring systems, herein called bucky-bow springs or "series" bow springs, can be used for extreme landing protection such as with parachute landing or jumping from heights, and the full-body harness described herein can also be used for these applications. It is hoped that this invention will provide enjoyment and injury-free exercise for people who love to run.

The above description shall not be construed as limiting the ways in which this invention may be practiced but shall in inclusive of many other variations that do not depart from the broad interest and intent of the invention.